THE METABOLISM OF RADIONUCLIDES BY MARINE ORGANISMS. II. THE UPTAKE, ACCUMULATION, AND LOSS OF YTTRIUM[91] BY MARINE FISH, AND THE IMPORTANCE OF SHORT-LIVED RADIONUCLIDES IN THE SEA [1, 2]

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A study of the metabolism of radioyttrium is important for two reasons: first, yttrium^{90} occurs as the daughter of long-lived strontium^{90}, an element which has considerable interest from the standpoint of public health, and second, yttrium^{91} occurs as a direct fission product to the extent of about four per cent of the total radioactivity present in a fission product mixture one year old. Fission products are being introduced into the seas to a small extent as a result of fall-out, and also from nuclear reactor plants located near the seaboard. The latter situation now occurs in the Irish Sea near Harwell, and more activity of this type may occur as reactor plants increase in number. Spooner (1949), in a noteworthy study on the metabolism of radioyttrium by marine algae, showed that this element was capable of being concentrated by certain algae, and thus stimulated the interest of marine biologists to learn more about the metabolism of the nuclide of mass^{90}.

Because we had begun experiments on the metabolism of strontium^{89} and strontium^{90}, both of which contain a certain amount of yttrium^{90}, we were interested in comparing the metabolism of these two elements in marine fish. Although the ratio of Sr^{90}: Y^{90} in an equilibrium mixture is about 3000: 1, it was conceivable that some of the results we obtained might have come from the small amount of yttrium present.

In a number of instances the concentration of certain elements is sometimes greater within a marine organism than it is in the surrounding sea water (Noddack and Noddack, 1939; Vinogradov, 1953). For example, one cannot predict, let alone explain, why one species of green algae will accumulate yttrium almost exclusively from a mixture of strontium and yttrium, while another accumulates strontium exclusively. Thus, Rice (1956) reports that *Carteria* sp. takes up 100 per cent of its radioactivity from the strontium in a Sr^{90}–Y^{90} mixture, but *Chlorella* sp., which is also a member of the Chlorophyceae, has 95 per cent of its radioactivity in the form of yttrium. Such tremendous differences in accumulation cannot be explained on the basis of size, that is, surface per gram protoplasm. Rather, the explanation is more likely to be one involving the chemical nature of the surfaces among the different algae. Because closely related algae are able to concentrate one element more than another, it is not unreasonable to suspect that one organ of a fish might have a greater avidity for yttrium than it has for strontium. Unfor-

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tunately, the small size of the fish used in these experiments did not permit us to separate the visceral organs in detail, so that we can only report the amount of radioactivity found in the integument, skeleton, gills, muscle, and in the combined visceral organs.

Materials and Methods

Yttrium^{91}, obtained from Oak Ridge, was incorporated into a two per cent gelatine solution, and 0.5 ml. was drawn up into a piece of Tygon tubing of small diameter. When the solution solidified, it was extruded directly into the fish's stomach with the aid of a syringe. The dose was 5.5 microcuries. The fish used were *Tilapia mossambica,* each of which weighed about 100 grams. After the radioyttrium was administered, three fish were put into a single carboy with 20 liters of sea water which had been filtered through a No. 4 Mandler filter. Four carboys were used for the four time intervals of 1, 2, 4 and 14 days. The water was aerated, but the fish were not fed. Twenty-four hours after the administration of the yttrium, the fish were put in tanks with running sea water where they were kept until killed rapidly by flooding the gill chamber with ether. After removing the eyes and the visceral organs, the remainder of the fish was put in a pressure cooker which was brought to 20 pounds pressure and then allowed to cool. This process allows the skeleton and integument to be separated easily from the muscle with no leaching of the radioisotope. The separated organs and tissues were dried and ashed at about 550° C. The ash was spread on aluminum planchettes with the aid of a wetting agent, dried under infra-red lamps, and counted with a G-M tube and a conventional scaler for a minimum of 2560 counts. Yttrium^{91} has a maximum energy of 1.5 Mev. No corrections were made for the self-absorption which was very small at the densities employed (< 6 mg./cm.^{2}). An aliquot of the dose was counted for reference and to correct for decay.

Results

Figure 1 shows that radioyttrium is very rapidly excreted by *Tilapia.* After two days, the fishes retained only about two per cent of the ingested dose (1.6 ± 0.5). In a similar experiment, the average amount of Sr^{89} retained by *Tilapia* after two days was 20 per cent, and even after 14 days, the average retention was about six per cent (Boroughs, Townsley and Hiatt, 1956). The actual absorbed dose may be something less than these values, because marine fishes swallow water in order to maintain their osmotic balance. A small amount of recently swallowed water would therefore be trapped in the gut unabsorbed, but contributing to the radioactivity in the visceral organs. Any feces remaining in the gut would also add to the radioactivity of the visceral organs. In both instances, however, the amount would be small.

Figure 2 indicates that most of the yttrium is retained in the viscera. In rats, the liver, kidney and spleen accumulate yttrium (Hamilton, 1948), but our methods did not permit us to localize the accumulation of yttrium in the visceral organs. Future experiments to disclose this are underway. Assuming that all the radioactivity recovered in the 14-day fishes was absorbed (1.3 per cent of the dose), the viscera retained 43 per cent, the muscle 29 per cent, the skeleton 16 per cent, the integument 8 per cent, and the gills 4 per cent. The large percentage of yttrium accumulated in the fish muscle was wholly unexpected, for in rats 65 per cent of the absorbed dose was found in the bones (Hamilton, 1948).

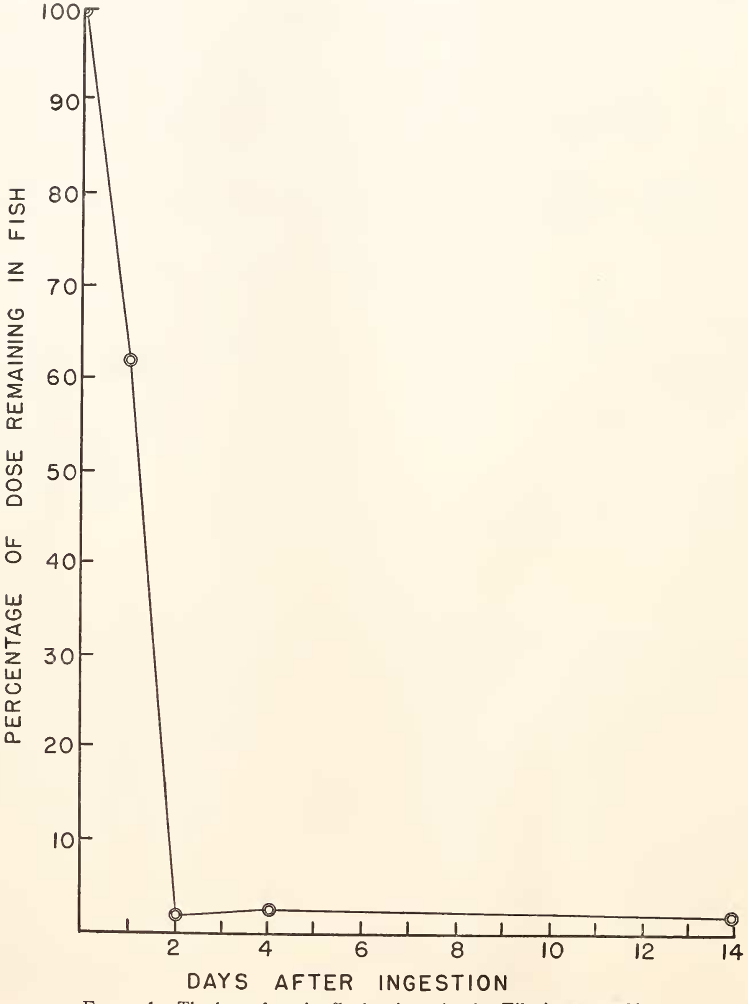

FIGURE 1. The loss of yttrium^{91} after ingestion by *Tilapia mossambica*.

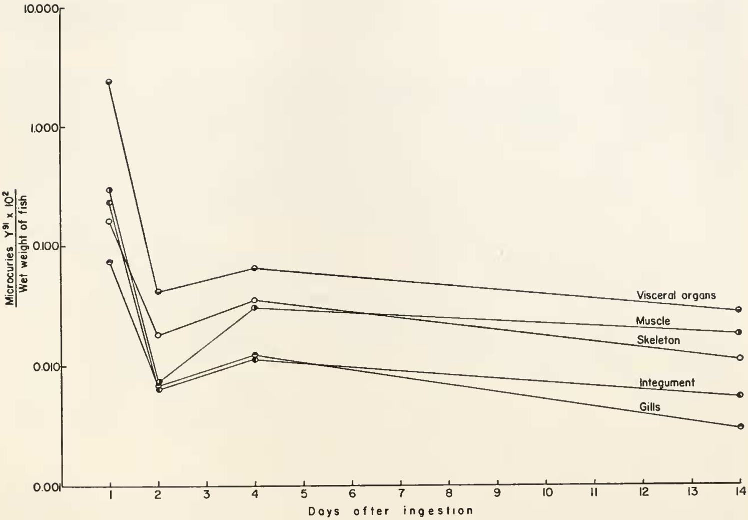

FIGURE 2. The internal distribution of yttrium^{91} fed to *Tilapia mossambica* via stomach tube.

DISCUSSION

Similar experiments with radiostrontium (Boroughs, Townsley and Hiatt, 1956) have indicated that in 14 days, *Tilapia* have about 60 per cent of the absorbed dose in the skeleton, 28 per cent in the integument, 9 per cent in the gills, 2 per cent in the muscle, and 1 per cent in the viscera. The rapid excretion of radioyttrium by *Tilapia,* coupled with the different patterns of internal distribution, indicate that the metabolism of strontium and yttrium in this species is markedly different. However, this is not too surprising in view of the difference in chemical behavior between these two elements. Studies on the accumulation of strontium by pelagic fish (Boroughs, Townsley and Hiatt, 1956) showed that this element is rapidly absorbed by all the tissues, but is also rapidly lost from the visceral organs and the blood. Similar experiments with *Tilapia,* a small sluggish fish, were unsatisfactory because of the large variability in the amount of Sr^{89} absorbed over periods up to 24 hours. We therefore made no attempt to follow the pathway of yttrium immediately after ingestion, but very likely yttrium is not actually absorbed to the extent that is strontium. At 24 hours, about 60 per cent of the dose was still in the entire fish, but most of this was in the gut. However, at least 5 per cent of the dose was absorbed by the muscle alone. This is at least 100 times more than the amount absorbed by rats from an oral dose (Hamilton, 1948), and, moreover, represents a minimum value for *Tilapia.*

The maximum percentage of ingested strontium which was recovered in the feces of *Tilapia* during 24 hours was less than 1 per cent. The feces were removed six or seven times during this interval, but some leaching of Sr^{89} may have occurred.

The percentage of Y^{91} recovered in parallel experiments has been as much as 20 per cent of the dose.

If the length of time required for an organ to excrete one-half of its concentration of a particular element is very long (biological half-life), then the effective biological half-life approaches the half-life of the radioisotope involved (radioactive decay). Elements which lodge in mammalian bones appear to have a very long biological half-life. According to Figure 2, however, the biological half-life of yttrium in all the tissues of *Tilapia* is of the order of one month. This value is of course only a guess, and long term experiments will have to be carried out to verify this estimate. In man, the body burden tolerance for Y^{91} is given as about 15 times that of Sr^{90} (N.B.S. Handbook 52), and in both instances the bulk of the radioactivity appears in the skeleton. In one year, the radioactivity owing to Y^{91} would be reduced to a negligible amount because of both excretion and decay, but very little Sr^{90} would be lost in this time. However, in organisms other than man, particularly marine organisms, one year may be a substantial part of their life span, and it is for this reason that we urge that attention be paid to the metabolism of radioactive fission products other than strontium. While strontium may constitute the most serious *direct* health hazard to man, long term effects of other shorter-lived fission products may have significant effects on the shorter-lived biota, and thus ultimately may also prove of importance to man.

There is no evidence that the slight increase in the radioactivity of the oceans has as yet caused any adverse ecological changes. Moreover, there is no evidence that adverse ecological changes will occur even as a result of the introduction of much larger amounts of radioactivity from nuclear reactor plants which are certain to be established within the next decade or so. If the present power requirements of the world are to be met with the aid of atomic energy, it is likely that a sort of steady-state condition will occur with regard to the added radioactivity in the oceans—the result of a balance between the rate of introduction of radioactive wastes, the rate of physical decay, and the rate of biological turnover. It is therefore imperative that marine biologists study in great detail the problems of the uptake and accumulation of fission products, the transfer of these nuclides back and forth among the trophic levels, and the direct, long-term effects of the nuclides in specific regions. Estuaries and the littoral zone will most likely have a higher concentration of radioactivity than the open sea, and it is in these regions that the bulk of the world's marine resources is produced.

Summary

Only about 2 per cent of an ingested dose of $yttrium^{91}$ was left in *Tilapia mossambica* after two days. This is much less than the amount of strontium retained by *Tilapia* in similar experiments. About 40 per cent of the radioisotope remaining is found in the visceral organs, but the muscles retain about 30 per cent after 14 days. The skeleton retained less than 20 per cent, the integument about 10 per cent, and the gills 5 per cent. These findings are in marked contrast with those obtained with $strontium^{89}$ in similar experiments. Attention is focused on the fact that $yttrium^{91}$ may have little direct effect on man compared with the possible effects of Sr^{90}, but the retention of this and other short-lived fission products in

marine organisms having a brief life span may possibly affect the biota, and thus affect man indirectly.

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